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AN OPERATIONAL HYGIENE SURVEY FOR INORGANIC LEAD AT THE CFB NORTH BAY ARMOURY, INDOOR FIRING RANGE

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ABSTRACT

An occupational hygiene survey for inorganic lead was carried out, during two consecutive days of weapons firing in the indoor firing range of the recently completed Armoury at CFB, North Bay. Atmospheric air inside the range was monitored at ten different sampling point locations during the firing of 9 mm pistol (handgun) and .22 calibre rifle on each of two different days. On Day 1 of the trial, mean lead exposures found at the breathing zone of the shooters and range safety officer were determined to be 0.152 mg/m^3 for the .22 Rifle and 0.65 mg/m^3 for the 9 mm pistol over a two-hour period of weapons firing. Eight-hour time weighted averages (assuming zero exposure when not firing weapon) were 0.038 mg/m^3 for the .22 calibre Rifle and 0.163 mg/m^3 for the 9 mm pistol. In the case of the 9 mm pistol, the TWA exceeded the Current Occupational Safety and Health Administration (OSHA), Permissible Expocure Limit (PEL) of 0.05 mg/m^3 for an eight-hour day. On Day 2 of the trial with no cleaning/housekeeping procedures carried out after the first day of firing, mean levels were found to be 1.01 mg/m^3 for the .22 Rifle and 1.57 mg/m^3 for the 9 mm pistol. Based on an eight hour TWA, both these values are in excess of the PEL. A statistical comparison of the values, for each of the weapons, during the two different days of the trial demonstrated a highly-significant difference in lead levels between days ($p > 0.01$). The findings suggest that a major source of airborne lead in an indoor firing range could arise from the generation of secondary aerosols.

Recommendations are made regarding range housekeeping procedures, safe occupancy periods and the need for modifications/adjustments to the ventilation system.

OBJECTIVE

This study was conducted on the 18-19 May 82 at the request of the Director of Preventive Medicine (DPM), through Director of Construction Engineering Requirements (DCER), to determine if the existing ventilation system in the indoor firing range at the CFB North Bay Armoury is adequate to maintain an acceptable environment for users. In this study the potentially hazardous levels of inorganic lead were generated during the firing of the .22 calibre rifle and 9 mm pistol.

A further objective of this study was to characterize the potential exposure of range users in accordance with limits established by the US Army Health Services Command. Once the mean atmospheric lead concentration in the range is determined, these limits are used to set maximum allowable hours of exposure for each category of range user.

INTRODUCTION

The Canadian Forces requires that personnel be trained in the safe handling and firing of small bore weaponry. Year round training may be carried out in indoor firing ranges where atmospheric conditions can be maintained at comfortable levels. Indoor firing ranges are designed to protect personnel from stray projectiles and other such physical hazards but may not provide the necessary protection from aerosolyzed lead and the gaseous combustion products generated during firing.

When a weapon is fired, the burning of the primer results in the vaporization and fragmentation of the projectile which releases inorganic aerosolyzed lead. Carbon monoxide, oxides of nitrogen and sulphur, are liberated into the atmosphere as well.

In this survey, major emphasis was placed upon the potential hazard created by the generation of an inorganic lead aerosol. This contaminant was used to evaluate the efficiency of the existing ventilation system in providing an occupationally healthy environment for the shooters and range control personnel.

Prolonged absorption of lead or its inorganic compounds from inhalation of vapour, fume or dust, as well as from oral ingestion, can result in severe gastro-intestinal disturbances and anemia with symptoms of anorexia, constipation, abdominal discomfort, weakness, fatigue, malaise, headache and pallor.

The current permissible exposure level (PEL) established by the U.S. Occupational Safety and Health Administration (OSHA) for inorganic lead is 0.05 mg/m^3(1). This value is designed to protect the health of the employee for eight-hour time weighted average exposures.

METHODS

Description of Indoor Range

The indoor range evaluated in this study was located in the recently completed Armoury, CFB North Bay. The range is approximately 28.9 meters (95 feet) long, 4.8 meters (15 feet, 9 inches) wide and 2.9 meters (9.5 feet) high. At a distance of 22.8 meters (25 yards) from the target/butt area two platforms are located which can accommodate up to four shooters. There are no plans to have firing booths installed in the range. The general plan of the range is illustrated in Figures 1, 3 and 4.

Description of Ventilation System

A diagramatic illustration of the ventilation system of the

firing range is shown in Figure 1. A supply of make-up air is introduced into the range by means of a duct 406 x 762 mm (16 inches x 30 inches) running the width of the room. This supply duct is located at the rear of the range. Conditioned make-up air was supplied to the range through three (3) 406 mm x 406 mm (16 in x 16 in) grills on the supply duct. Prior to entry into the range, the supply air entered a compartment having an approximate volume of 3.27 m^3 then passed through a wooden wall panel having holes 19 mm in diameter with 51 mm centres, before entering the range.

Air was extracted from the range by means of a duct located in the ceiling at the target area. This duct was tapered, having a cross-sectional area of 470 mm x 406 mm (18.5 in x 16 in) at the right hand side and 762 mm x 406 mm (30 in x 16 in) at the left hand side of the target area. This duct was fitted with four 292 mm x 1130 mm (11.5 in x 44.5 in) side-mounted grills. At mid-range, the air was exhausted from a wall-mounted grill dimensions of 533 mm x 559 mm (21 in x 22 in). This grill was 203 cm (6 ft. 8 in) above floor level.

The air flow through each of the supply air and extraction grills was measured at the time of the survey using an Alnor Velometer (Model 6000P, manufactured by Alnor Instrument Co., Chicago, U.S.A.). The air flow through the supply and exhaust grills was determined by averaging six (6) separate readings for each of the three (3) supply grills, twenty-four (24) separate readings for each of the four target area exhaust grills and nine (9) separate readings for the mid-range exhaust grill. In addition, a pitot traverse was conducted to measure the air flow through the exhaust duct at the target area (2).

Weapons, Ammunition, and Firing Conditions

A description of the weapons, ammunition and conditions of firing employed in this trial is as follows:

Weapons

.22 Rifle - Standard FN-Cl, 7.62 mm, semi-automatic with the Heckler-Kosh sub-calibre insert .22 calibre.

9 mm (Parabellum) - Bullet weight 125 grains military ball.

Rate of Firing

Weapon Type	Rounds/hour/shooter	No. of Shooters	Total Rounds for 2-hour Period
.22 Rifle	110	4	880
9 mm Pistol	100	4	800

Test Sequence

This survey was conducted over two consecutive days. During each of the days, conditions of weapons firing and ventilation were maintained the same. However, on the first day, since the range had never been used previously, it was presumed that it was free from any inorganic lead deposits. On the second day, however, since no cleaning had taken place between days the aerosolyzed lead, not removed by the ventilation system, would have settled throughout the range.

The weapons employed were the .22 calibre rifle and the 9 mm pistol. On each test day air sampling was carried out over a 3-hour period for the .22 calibre rifle, and a 4-hour period for the 9 mm pistol.

Weapons firing was carried out during each of the test sequences by four militia volunteers from the Algonquin Regiment. Range Safety Officers were selected from militia volunteers and regular support staff personnel. During the two-hour firing period for each weapon, sampling for inorganic lead was carried out by means of personal monitoring pumps with sampling filter cassette assemblies attached to each of the volunteer shooters. Each of the filter assemblies was located in the vicinity of the individual's breathing zone. Personal samples were thus taken from the shooters and the range safety officer.

A sampling strategy was employed to conform with that proposed by the US Army (3) to evaluate an indoor range for maximum occupancy period, based on lead concentrations. Sampling points were located 10 feet behind the firing line, at the firing line and at the butt area in this study. In addition, one sampling point was located in an area adjacent to the range to determine whether lead contamination was confined to the range proper. The location of these sampling points, with the exception of the external sampling point, are illustrated in Figure 2.

At the beginning of each test day, before any firing occurred, lead determinations were performed over a one-hour sampling period at two sampling points in the range. In the case of the 9 mm pistol, sampling was continued for a one-hour period immediately following cessation of firing. The sampling points were located approximately one meter in front of the butt area and at the firing line. In this fashion samples were taken to establish the background levels of inorganic lead prior to weapons firing and levels following completion of firing.

For purposes of this study, mean on-line inorganic lead concentrations were determined using personal sample values of the four shooters as well as the range safety officer. These concentrations

were used to establish safe occupancy periods.

Air Sampling Methods

Aerosolyzed Inorganic Lead

Sampling for aerosolyzed inorganic lead was carried out, by drawing air through filters with the aid of personal sampling pumps. Five pumps, manufactured by Bendix (BDX-44), were utilized to monitor the lead levels in the vicinity of the breathing zones of each of the four shooters and the range control officer (SP 1 to 5, Fig. 2). Four Dupont (P-4000) pumps were similarly used to monitor the lead at the four fixed sampling points (SP 6 to 9) previously described. For SP10 and the area adjacent to the range sampling point, Bendix (BDS-44) and Gillian Model HFS 113U pumps were used respectively. Each pump was calibrated to sample at a rate of 2L/min, utilizing a Kurz Model 540 mass flowmeter. Calibration of each pump used was carried out both prior to and immediately following the total sampling period.

The aerosolyzed lead was collected on cellulose nitrate membrane filters manufactured by Glasrock Incorporated, Atlanta, Ga, USA, having a 0.8 um pore size. Each filter was encased in a 37 mm three-piece plastic field monitoring cassette. Immediately prior to the commencement of sampling, the plastic plugs sealing each cassette were removed and the cassette was connected to the sampling pumps by means of a short piece of tubing for the two-hour sampling period. Each cassette containing a collected sample was re-sealed, labelled and transported back to the laboratory for analysis. Analysis of each filter for its inorganic lead content was subsequently carried out by means of filter acid digestion and atomic absorption spectrophotometry.

RESULTS AND DISCUSSION

Inorganic Lead Levels

The results obtained from sampling the atmosphere within the range before, during and post weapons firing, for aerosolyzed inorganic lead on two different trial days are shown in Tables 1 and 2. The highest concentrations of lead were found on Day 2 of the trial on personal samples during the test employing the 9 mm pistol. These values ranged from a low of 0.75 to a high of 2.00 mg/m^3 with a mean of 1.57. The lowest personal sample concentrations were found during Day 1 of the trial when firing the .22 calibre with a mean value of 0.152 mg/m^3 (range 0.12 - 0.19). At the same time on both days the area samples 10 ft behind the firing line were all less than 0.004 mg/m^3. This is attributed to a high down-range air flow at this point due to its close proximity to the air supply system. All background and post firing levels were less than 0.004 mg/m^3 (limits of detectability of analytical method), with the exception of the

post firing value, 0.0127 mg/m^3, obtained following 9 mm firing on Day 2 of the trial.

Although it is evident that all mean values found during this study are above the PEL, the sampling period during weapons firing was two hours only, and does not represent the full eight hour period required for the time weighted average (TWA) calculation. Assuming the remainder of the day is zero exposure, the time weighted averages for the .22 calibre (Day 1) and the 9 mm (Day 1) are 0.038 and 0.162 mg/m^3 respectively. In the case of the .22 rifle the TWA is below the standard and does not constitute a hazard, whereas the 9 mm value is above the TWA and is in violation of the existing occupational health standard of 0.05 mg/m^3.

The large difference in lead concentration obtained between the two days of the trial, with the same weapon is most likely due to the fact that no cleaning/housekeeping was carried out following completion of firing on Day 1 or prior to firing on Day 2. It is interesting to note that all background (prefiring) samples were negative for inorganic lead. However, once firing commenced, inorganic lead aerosol that had settled during the non-firing period became airborne by a combination of weapons firing and movement of personnel to and from the firing line and target area.

Statistical analysis of the lead levels measured at each of the four shooter positions and including the range safety officer indicated there was a highly significant difference between days for each of the two weapons assessed. No significant difference was noted between shooter locations for each type of weapon employed (Tables IV and V).

Ventilation

Air velocity measurements obtained in the range at the time of the study appear in Table 1. The total make-up air and total exhaust air volumes were 11,618 CFM (330 m^3/min) and 9,410 CFM (267 m^3/min) respectively. Eye level air velocity at the firing line was found to be 40-50 fpm (0.2 - 0.25 m/sec).

The basic requirement for indoor firing range ventilation is to have fresh uncontaminated air supplied behind the firing line and exhausted at a point beyond the firing line and at the butt area. The design that provides the best results is one that exhausts 20-40% of the air in front of the shooters and 60-80% at the bullet trap. It is also strongly recommended that the exhaust air exceed the supply air by at least 10% to create a slight negative pressure inside the range so that lead fumes will not escape into other parts of the building (4). In the case of the North Bay Armoury, the percentage exhausted at the midrange point was 25.4% and at the butt area 74.6%. These values compare favourably with values recommended

at Reference 4. However in comparing the exhaust and supply air volumes it can be readily seen that there is a positive pressure in the range. This was readily observed, at the time of the survey, by using smoke tubes in the vicinity of the range exit door.

Maximum Allowable Exposure Table

To adequately characterize the potential exposure of range users and range control personnel the US Army has developed an airborne lead sampling strategy (3). These exposure limits are based on current OSHA standards for both air and blood levels. The sampling strategy is based upon individual activity, weapons used and period of participation in weapons firing. Once an airborne lead concentration in the range is determined, the maximum allowable hours of exposure for range users may be selected from Table VI.

The duration of sampling described in this report is based on existing Canadian Forces range usage and was for a 2 hour sampling period during light (.22 Rifle) and heavy (9 mm) weapons, with sampling point locations both on the firing line and 10 feet behind the line. Sampling during weapons firing was carried out in accordance with US Army Sampling Strategy as previously described in the methods section.

In reference to Table VI extracted from Ref. 3 it can be seen that the maximum allowable exposure period for the mean value of 0.152 mg/m^3 obtained on Day 1 of the trial for the .22 rifle is (6 hours/week or 3 hours/day) when firing 30 or more days/year. In the case of the 9 mm pistol on Day 1 of the trial, it can be seen that the maximum allowable exposure period, for the mean lead value of 0.65 mg/m^3 is 1.5 hours/week or 0.5 hours/day when firing 30 or more days per year as well as firing less than 30 days/year. It is unlikely, in the CF situation, that any member would be required to remain in the range for a period greater than the exposure time allowed for range qualifications suggested in Table VI.

RECOMMENDATIONS

1. From the results obtained during this two day evaluation of the Indoor Firing Range, CFB North Bay Armoury, it is evident that the concentrations obtained for the 9 mm pistol are excessive and above the existing standard. Occupancy of the range should not exceed the periods recommended in Table VI.

2. Values obtained for the .22 calibre for the two hour assessment period are not in violation of the standard of 0.05 mg/m^3. However, the maximum allowable exposure period, for the concentration obtained, should not be exceeded.

3. At the time of the study air velocity measurements established that a positive pressure existed in the range. Air flow should be modified to ensure that a slight negative pressure (10%) will occur to prevent contamination of adjacent areas of the range.

4. It is recommended that the air velocity at the firing line be increased from the measured 50 fpm to 75 fpm, thus decreasing inorganic lead exposure to the shooter (Reference 4).

5. Based on the highly significant difference of lead concentrations between two days of firing, it is recommended that thorough cleaning of the range should be carried out between each shooting session.

6. It is recommended that cleaning staff be provided with adequate respiratory protection and perform cleaning procedures using vacuum cleaning or wet methods (Ref. 5).

7. Based on the atmospheric air inorganic levels found in the range at the time of the trial and the non-regular type exposure of the military range user it is recommended that biological monitoring not be considered essential. However, in the case of the permanently assigned (i.e., janitorial staff) it should be mandatory to have biological monitoring carried out in accordance with CFMO 40.05.

REFERENCES

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4. US Department of Health and Human Services, NIOSH Technical Assistance Report 80-79-753, October 1980.

5. US Department of Health Education and Welfare. HEW Publication NO. (NIOSH) 76-130. Lead Exposure and Design Considerations for Indoor Firing Ranges.

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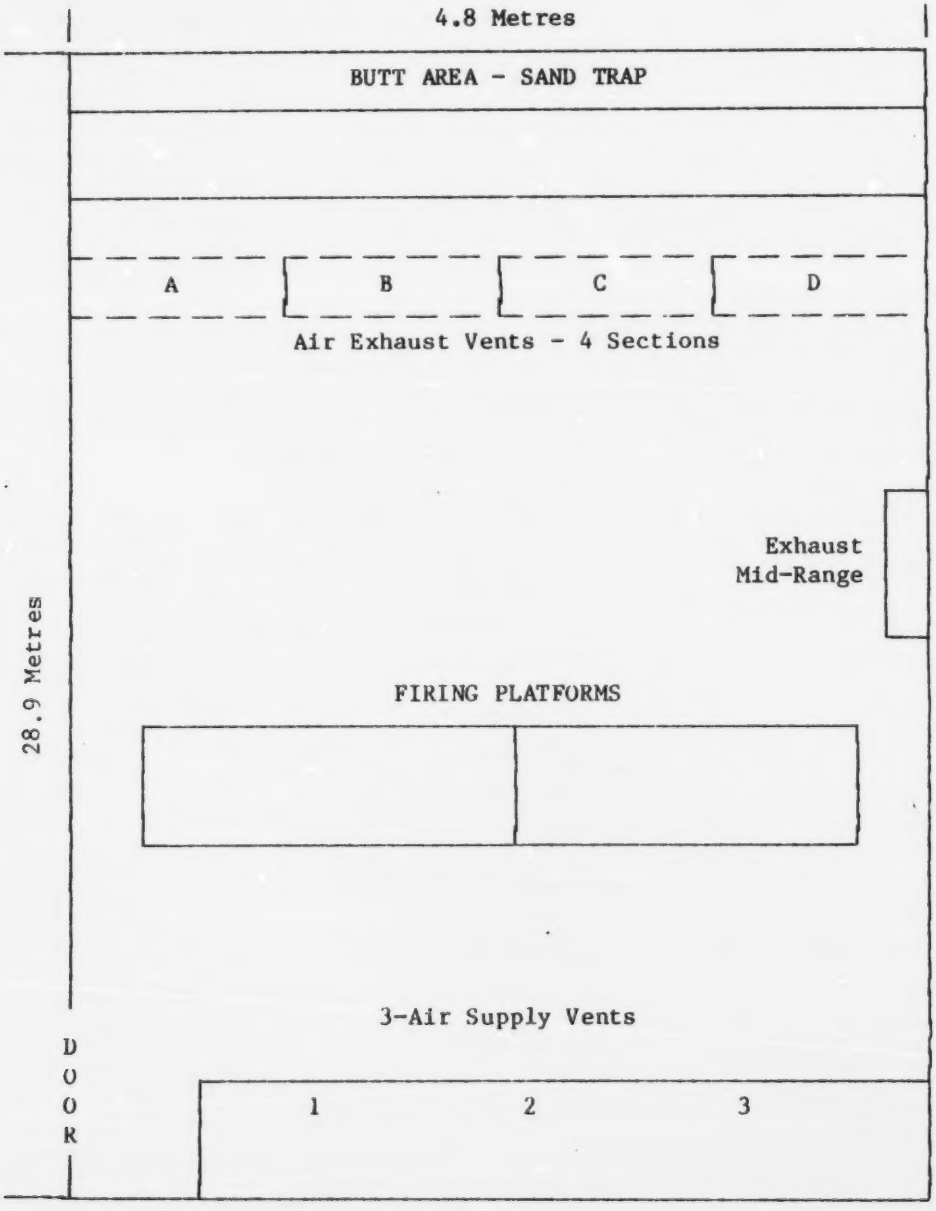
Figure 1

PLAN FOR INDOOR CFB NORTH BAY - ARMOURY

FIRING RANGE



* Drawing not to scale

Figure 2

SAMPLING POINT LOCATIONS FOR INORGANIC LEAD DETERMINATIONS

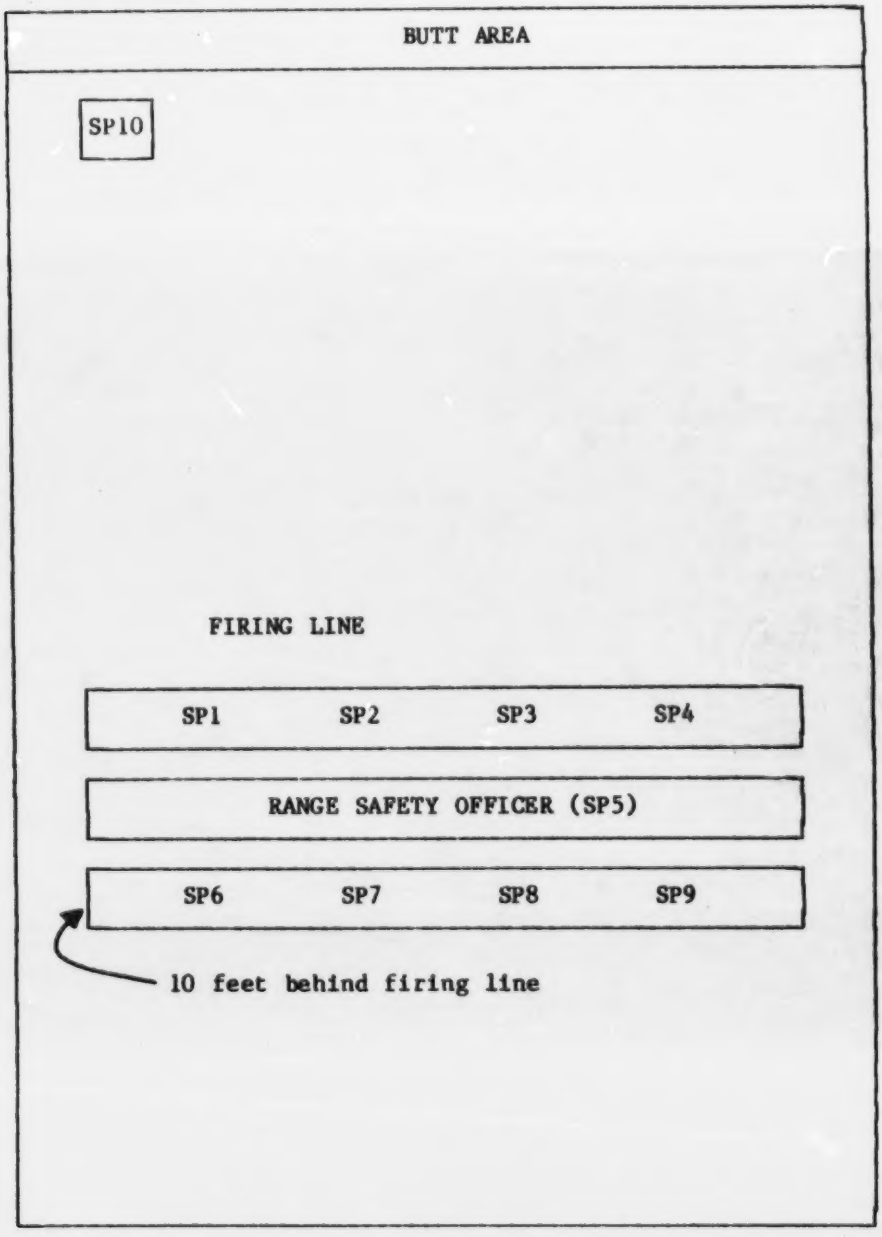


Figure 3

Downrange view of Indoor Firing Range, CFB North Bay Armoury, illustrating shooter positions.

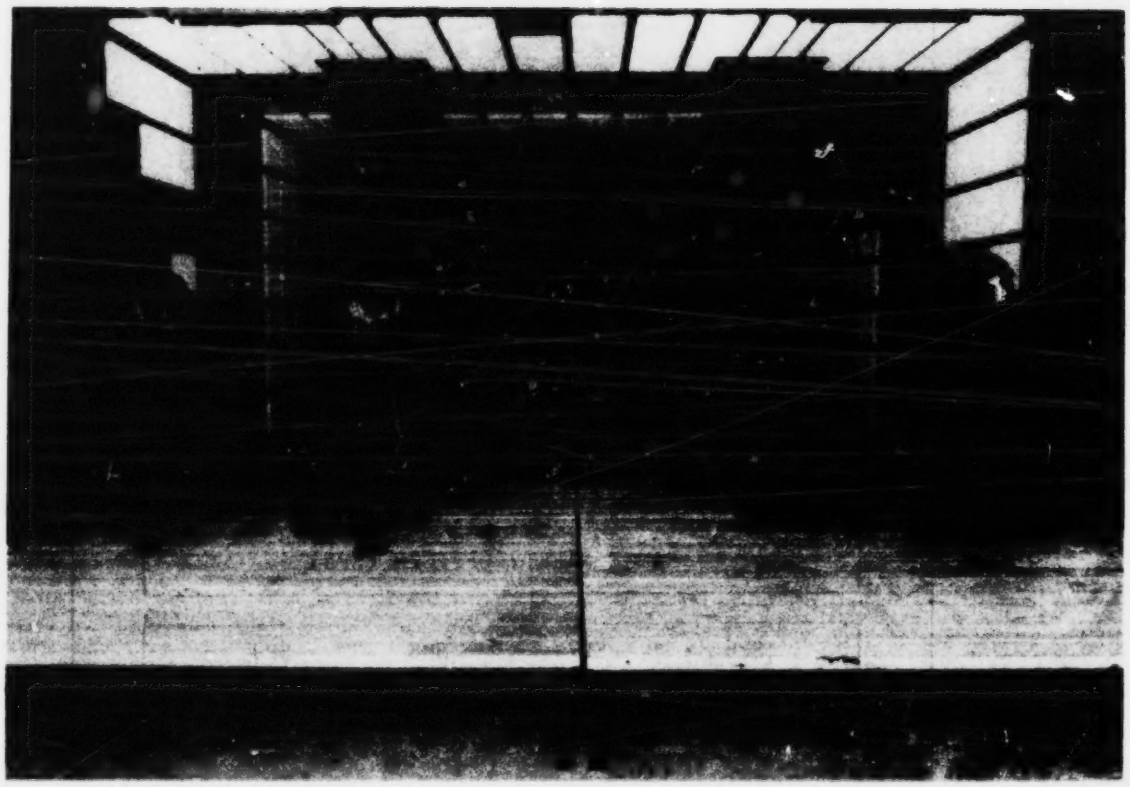


Figure 4

Downrange view of Indoor Firing Range, CFB North Bay Armoury, illustrating sampling point locations behind the firing line.

Table 1

Personal and Area Sample Inorganic Lead Concentrations (mg/m^3) During Weapons Firing

Weapon Type	Trial Date-Time	Sampling Period	Personal Sampling Point Locations					Area Sampling Point Locations			
			1	2	3	4	5	6	7	8	9
.22 Rifle	Day 1 PM	2 Hours	0.19	0.16	0.13	0.12	0.16	0.004*	0.004	0.004	0.004
9 mm Handgun	Day 1 Evening	2 Hours	0.95	0.38	0.50	0.74	0.67	0.004	0.004	0.004	0.004
9 mm Handgun	Day 2 AM	2 Hours	1.70	0.75	1.72	2.00	1.70	0.004	0.004	0.004	0.004
.22 Rifle	Day 2 PM	2 Hours	1.02	1.22	0.95	1.02	0.85	0.004	0.004	0.004	0.004

* all values less than 0.004

Table II

Pre- and Post-Firing
Area Sample Inorganic Lead Concentrations (mg/m^3)

Weapon Type	Trial Date-Time	Sampling Period	Area Sampling Point Locations				
			SP6	SP7	SP8	SP9	SP10
.22 Rifle	Day 1 PM	Pre-firing	-----	< 0.004	-----	-----	< 0.004
		Post-firing	-----	-----	-----	-----	-----
9 mm Handgun	Day 1 Evening	Pre-firing	-----	< 0.004	-----	-----	< 0.004
		Post-firing	< 0.004	< 0.004	< 0.004	< 0.004	-----
9 mm Handgun	Day 2 AM	Pre-firing	-----	< 0.004	-----	-----	< 0.004
		Post-firing	< 0.004	< 0.004	< 0.004	< 0.004	< 0.0127
.22 Rifle	Day 2 PM	Pre-firing	-----	< 0.004	-----	-----	< 0.004
		Post-firing	-----	-----	-----	-----	-----

TABLE III

Air Velocity Measurements Taken at Time of Survey for Inorganic Lead Concentrations

Air Supply Grills

Location	Vent Size mm	x fpm -- M/S		CFM --	m^3/min
1	406 x 406	2313	11.75	4112	117
2	406 x 406	1822	9.25	3239	92
3	406 x 406	2400	12.19	4267	121
				11,618	330

Air Exhaust Grills

Location	Vent Size mm	x fpm -- M/S		CFM --	m^3/min
Mid-Range	533 x 559	744	3.78	2387	68
Butt A[1]	152 x 1130	1550	7.87	2874	81
B	152 x 1130	1083	5.50	2008	57
C	152 x 1130	662	3.36	1227	35
D	152 x 1130	493	2.50	914	26
				9,410	267

[1] - Each of the 4 butt area exhaust grills had 8-19 mm fixed louvered openings

TABLE IV

Analysis of Variance of Inorganic Lead Concentration Produced by 9 mm Pistol on Two Different Days of Firing

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	Computed F
Days	2.14	1	2.14	31.24*
Location	0.83	4	0.208	3.03
Error	0.27	4	0.068	
Total	3.24			

* Highly significant at the 0.01 probability level.

TABLE V

Analysis of Variance of Inorganic Lead Concentration Produced by .22 Rifle on Two Different Days of Firing

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	Computed F
Days	1.84	1	1.84	202.63*
Location	.04	4	.01	1.09
Error	.036	4	.009	
Total	1.916			

* Highly significant at the 0.01 probability level.

TABLE VI

PERSONNEL EXPOSURE LIMITS FOR INTERMITTENT ATMOSPHERIC LEAD EXPOSURES

LEAD AIRBORNE CONCENTRATION (mg/m^3)			MAXIMUM HOURS OF ALLOWABLE EXPOSURE			
			FIRING 30 OR MORE DAYS/YEAR		FIRING LESS THAN 30 DAYS/YEAR	
>		≤	Hrs/Week	Hrs/Day	Hrs/Week	Hrs/Day
0	-	0.03	40	8	40	8
0.03	-	0.05	24	8	32	8
0.05	-	0.10	12	6	18	6
0.10	-	0.15	8	4	12	4
0.15	-	0.20	6	3	9	3
0.20	-	0.25	4½	2½	7½	2½
0.25	-	0.30	4	2	6	2
0.3	-	0.4	3	1½	4½	1½
0.4	-	0.5	2½	1	3	1
0.5	-	0.7	1½	½	1½	½
0.7	-	1.0	1	½	1	½
1.0	-	2.0	½	½	½	½
2.0	-	4.0	‡	‡	‡	‡
4.0			0	0	0	0

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